Optical anisotropy and light outcoupling in OLEDs

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Abstract- *Organic Light Emitting Diodes consist of a stack of thin layers that have a high refractive index and may have anisotropic optical properties. The emission from such a planar structure depends on the layering of the OLED, the anisotropy of the different materials and the orientation of the dipole emitters in the organic layer. OLEDs are used in lighting and display devices and the requirements for both applications are very different.*

With recent demonstrations of large TVs based on Organic Light Emitting Diodes (OLEDs), the world expects a lot from this technology in the near future. OLEDs can produce excellent dark states and can represent many gray levels, even in the dark region. The organic layers are very thin which makes displays on curved surfaces or on flexible substrates within reach. The requirements for the organic layer stack are very demanding:

- a well-defined current-voltage characteristic which is stable under dc forward bias;
- efficient generation of excitons;
- efficient radiative decay of excitons;
- good outcoupling of the photons towards the viewer.

Important advances have been made in efficient emitter materials, avoiding oxygen and humidity in the stack and improving the life-time. Because the refractive index of the emitting layer is relatively high, the outcoupling efficiency of a planar structure with randomly oriented emitters is limited to about 20% due to wave-guiding in the substrate, so a lot of improvement seems possible [Mladenovski, 2011 #5255].

One option is to break the planar symmetry of the OLED devices by including structures in the substrate [Callens, 2014 #5388]. Depending on the size of the structures, the light can be refracted (for large structures) or diffracted (for small structures) out of the substrate. Structures are great to increase the light output, which is the primary goal for lighting applications. For display applications the refraction or diffraction of light may yield unwanted optical effects [Lee, 2008 #5355].

Two kinds of optical anisotropy can occur: in the first kind, the materials are birefringent, as in a crystal or a liquid crystal, which means that the material can have two different refractive indices, depending on the polarization of the light that passes through it. In the second kind, the material is optically isotropic, but the emitting molecules have a preferred orientation, for example with their long axis parallel to the substrate.

In recent years evidence for oriented dipole emitters has been gathered. Because dipole emitters emit most of the photons perpendicular to the axis (just like macroscopic radio-antennas that are much smaller than the wavelength they emit) it is preferred to orient them with their axis parallel to the substrate. This orientation leaves its mark on the angle dependency of the emission [Schmidt, 2011 #5185] and on the decay rate of the emitters [Penninck, 2012 #4520]. By now it is clear that some emitting molecules orient randomly on the substrate when they are evaporated, while others molecules prefer a planar orientation. Obviously this is to some extent correlated with the shape of the emitting molecules [Yokoyama, 2011 #5345].

Not only the emitter materials can have an anisotropic orientation, also the embedding host material may consist of anisotropic molecules that orient in a certain way when they are deposited. The result is that the material itself becomes anisotropic with different polarizabilities parallel and perpendicular to the substrate. The light propagation in the structure now has to be treated with an appropriate matrix algorithm. In addition, the dipole emitter is now immersed in an anisotropic medium which modifies the emission pattern.

The anisotropy of the emitting molecules and the optical anisotropy of layers have been included in a simulation program [Penninck, 2011 #5254]. The program has been tested by investigating the emission from strongly aligned dye molecules in strongly anisotropic liquid crystal mixture which gives satisfying results [Penninck, 2012 #5251]. The anisotropy of the materials, in particular of the host may be a promising route to further increase the efficiency of OLED devices.

In OLED displays, typically a circular polarizer is placed in front of the display to reduce the reflection of ambient light on metallic electrode and to increase the display's contrast[Singh, 2012 #5393]. However, it comes with high cost as typically around 60% of the randomly polarized light emitted from the OLEDs is absorbed by the polarizer [Singh, 2012 #5393]. For a required brightness of the display, some degree of polarization of the emission would help to minimize the losses in the polarizer, lower the current and increase the lifetime of the OLED.

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